DEVELOPMENT OF IMPACT STRENGTH MODEL FOR HUMAN SYNTHETIC BONE

NG KOK CHUAN

Thesis submitted in partial fulfilment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

DECEMBER 2010

SUPERVISOR’S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature

Name of Supervisor: Dr. DAW THET THET MON

Position: SENIOR LECTURER OF FACULTY OF MECHANICAL ENGINEERING

Date:

STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurently submitted for award of other degree.

Signature
Name: NG KOK CHUAN
ID Number: MA07039
Date:

ACKNOWLEDGEMENT

I am grateful and would like to express my sincere gratitude to my supervisor Dr. DAW THET THET MON for her invaluable guidance and constant support in making this thesis. This thesis could not been done without her who not only served as my supervisor but also encourage me throughout the process. I also would like to express very special thanks to the panel member who give valuable comment and suggestion during my project presentation.

My sincere thanks go to all laboratory assistant from Faculty of Mechanical and Faculty of Manufacturing, Universiti Malaysia Pahang for their teaching and help during the period of my project.

I acknowledge my sincere indebtedness and gratitude to my parents, Mr. NG KIM LING and Mdm. SEOW YOK KUAN for their love and sacrifice throughout my life. They have always supported my dreams. They did a fine job raising me.

ABSTRACT

Due to current demand, the usage of synthetic bone had increased dramatically during these recent years. The main purpose of this project is to develop and analyze the impact strength model for human synthetic bone. The impact test simulation was done in finite element analysis (FEA). The bone model geometry will be designed in Solidwork environment and imported into finite element environment for FEA Finite element analysis will be carried out in MSC. Patran/Marc and Algor respectively. Major input data to FEM were isotropic material model, solid element type (tetrahedral in MSC. Marc and brick in Algor), constraints and impact load. Material properties were taken from literature. The model were validated with published experimental results. Predicted stress-strain response of synthetic bone was agreeable with published report. Based on the analysis results, MSC. Marc model is better than Algor. The result obtained shows the response of synthetic bone towards impact loading.

ABSTRAK

Dengan timbulnya permintaan semasa, permintaan terhadap penggunaan tulang sintetik meningkat secara mendadak sejak beberapa tahun yang lepas. Matlamat utama projek ini adalah untuk mengembangkan dan analisa kekuatan impak modal untuk tulang sintetik manusia. Simulasi ujian impak telah dijalankan dengan menggunakan FEA. Geometri tulang akan dibentuk dalam Solidwork dan diimport ke FEA. FEA akan dijalankan di MSC. Patran/Marc dan Algor. Data utama ke FEM adalah bahan modal isotropik, elemen pepejal (tertra dalam MSC. Marc dan bata dalam Algor, batas dan bban impak Sifat bahan diambil dari sastera. Model tersebut disahkan dengan keputusan experimen yang diterbitkan. Respon stress-tegang yang dijangka adalah dipersetujui dengan laporan yang diterbitkan. Berdasarkan keputusan analisa, modal MSC. Marc adalah lebih baik daripada modal Algor. Keputusan dari analisa menunjukkan penbalasan untuk tulang sintetik manusia terhadap impak.

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LIST OF SYMBOLS

L	Lagrangian
T	Kinetic energy
π	Potential energy
m	Mass
v_o	Velocity
E	Modulus of elasticity
V	Volume
P_m	Static force
L	Length
I	Moment of inertia
U_m	Strain energy
C	Radius
V_e	Element volume

LIST OF ABBREVIATIONS

FEA	Finite element analysis
TCP	Tricalcium phosphate
CAE	Computer Aided Engineering
CAD	Computer Aided Design
MSC	MacNeal-Schwendler Corporation
FEM	Finite element method

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Almost all livings thing such as animals & humans have bones. Bones are rigid organs that form part of the skeleton. Bones can produces red and white blood cells and store minerals. Bones come in a variety of shapes to fit different area of the body as it provides a frame to keep the body supported. Bone is light in weight yet strong and hard. There are 206 bones in a human adult body and 270 in a human infant body. Bones serves as protection for internal organs, such as the skull protecting the brain. Bones combine and function together to generate and transfer forces so the human body parts can move in three-dimensional space. Daily activities pose danger to the bones where fracture might occurs due to various type of loading or force particularly heavier action and more extreme activities in current society increase the chances for bone fracture (The anatomy and biology of the human skeleton).

Artificial bone has been developed using bone-like material. It has now played an important role in bone graft procedures which replace human bone that was lost due to fracture. There are many researches done to develop one similar to natural bone in effort to maintain its functions in the human body. For example, artificial bone has porous structure which allows the growth of blood vessels. Bone properties are important to withstand different kinds of load especially impact load which is the main cause of fracture. Impact loading is the dynamic effect on a body and a forcible momentary contact of another moving body. The bone, however protected is very vulnerable to impact load. In this regard, knowledge of bone respond to impact load would be useful to improve bone properties. Unfortunately in literature, only limited study has been done to find out bone respond and these are typical tensile or compression test because of it being an expensive research and difficult to obtain natural bone test specimen.

In this project, the synthetic bone will be tested to develop impact strength model since it has similar properties to natural bone. Thus, it can show similar test result and respond for natural bone. This synthetic bone is commonly used in bone grafting operation for human. Finite element analysis is carried out to simulate the response of synthetic bone to impact load.

1.2 PROBLEM STATEMENT

Human are highly exposed to danger that might cause bone fracture especially from accidents. Accidents can be in form of car crash, fall from higher place, and extreme sports. As such, demands of bone grafting a process of replacing artificial bone have been increased. . There are many efforts to create artificial bone which is similar to natural bone or even a more improved bone property. An important property of artificial bone is the ability to withstand high impact loading. However the strength of artificial bone to withstand high impact loading is relatively unknown. The experimental study alone is expensive due to high cost of the specimen.

1.3 OBJECTIVES

Objectives for this project refer to the mission, purpose, or standard that can be reasonably achieved within the expected timeframe and with the available resources. The objectives of this project are:

1. To develop the finite element model that can predict impact strength of human synthetic bone.
2. To validate finite element model with experiment.
3. To investigate predicted stress-strain responds of synthetic bone under impact load.

1.4 PROJECT SCOPES

The scopes for this project are:

1. Bone geometry will be constructed using Solidwork.
2. Finite element model will be developed in MSC. Patran and Algor.
3. Impact analysis will be carried out in MSC. Marc and Algor.
4. Finite element model will be validated with published experimental result.
5. Stress-strain relationship due to impact load will be plotted in Excel.

Bone model size is scaled down to 12.5% of the actual one to resolve the meshing problem in finite element model. Two finite element codes are tested to compare its predictability. Solidworks model is imported to finite element environment for finite element modeling in MSC. Marc and Algor.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will provide the detail description literature review done according to title of development of impact strength model for human synthetic bone. Literature regarding any development or experiment about bone properties is useful in this project. This is includes the bone sizes or shapes available at current market, synthetic bone material, type of test such as compression and impact, and finite element software available for analysis.

2.2 NATURAL BONE

The primary tissue of bone, osseous tissue, is a relatively hard and lightweight composite material, formed mostly of calcium phosphate in the chemical arrangement termed calcium hydroxylapatite (this is the osseous tissue that gives bones their rigidity). It has relatively high compressive strength, of about 1800 kg/cm^2 but poor tensile strength of 104-121 MPa, meaning it resists pushing forces well, but not pulling forces. While bone is essentially brittle, it does have a significant degree of elasticity, contributed chiefly by collagen. All bones consist of living and dead cells embedded in the mineralized organic matrix that makes up the osseous tissue. Bone is not a uniformly solid material, but rather has some spaces between its hard elements. The hard outer layer of bones is composed of compact bone tissue, so-called due to its minimal gaps and spaces. Its porosity is 5-30%. This tissue gives bones their smooth, white, and solid appearance, and accounts for 80% of the total bone mass of an adult skeleton. Compact bone may also be referred to as dense bone. Filling the interior of the bone is the trabecular bone tissue, which is composed of a network of rod- and plate-like elements that make the overall organ lighter and allow room for blood vessels and marrow. Trabecular bone accounts for the remaining 20% of total bone mass but has nearly ten times the surface area of compact bone. Its porosity is 30-90%. If for any reason there is an alteration in the strain to which the cancellous is subjected, there is a rearrangement of the trabeculae. The microscopic difference between compact and cancellous bone is that compact bone consists of haversian sites and osteons, while cancellous bones do not. Also, bone surrounds blood in the compact bone, while blood surrounds bone in the cancellous bone. Figure 2.1 shows section through the head of the femur, showing the cortex, the red bone marrow and a spot of yellow bone marrow. The white bar represents 1 centimeter. Specimen obtained after total hip replacement surgery, left hip (Basic Biomechanics).

Figure 2.1: Bone cross-section

Source: Wikimedia Commons

2.3 SYNTHETIC BONE DESIGN

There are many shapes and sizes of synthetic bone design. Available shapes can be granules, sticks, block, cylinder, and wedge. Sizes can range from 2mm to 14 mm for regular geometry. Different shapes and sizes serve different purpose or area of substitute in human bone. Figure 2.2 illustrates synthetic bone size and shapes available in the market today The synthetic bone is design with fully interconnected pores, having pore size between 200 to 500um, and mean porosity between 60 to 80 percent to resemble the real bone.

Ref.	Shapes	Sizes
K43105G-E	Granules	2-3mm [5cc]
K43110G-E	Granules	2-3mm [10cc]
K43115G-E	Granules	2-3mm [15cc]
K43120G-E	Granules	2-3mm [20cc]
K43105S-E	Sticks	5x5x20mm (box of 5)
K43115B-E	Block	15x15x20mm (box of 1)
K43120B-E	Block	15x20x30mm (box of 1)
K43106W-E	Wedge	6mm (box of 1)
K43108W-E	Wedge	8mm (box of 1)
K43110W-E	Wedge	10mm (box of 1)
K43112W-E	Wedge	12mm (box of 1)
K43114W-E	Wedge	14mm (box of 1)

Figure 2.2: Synthetic bone shapes and sizes.

Source: KasiosTCP 2010

2.4 SYNTHETIC BONE MATERIAL

A synthetic bone, so-called TCP as trade name is made of pure β-TCP which is calcium phosphate molecule similar to the mineral phase of the natural bone. Mode of operation in curing bone defects is highly bioactive. It undergoes total or partial resorption and is replace by neoformed natural bone. It is indicated for filling bone voids or defects of the skeletal system (such as the extremities, spine and the pelvis) that are not intrinsic to the stability of the bony structure. These defects may be surgically created osseous defects or osseous defects created from traumatic injury to the bone. Kasios TCP is a bone graft substitute that resorbs and is replaced with bone during the healing process.

It has many features and benefits including no reaction to foreign body, can be replaced by natural bone, encourages a quick and proper osseointegration, no risk of immune response, no risk of cross contamination, no risk of disease transmission, decrease surgery time, allows for a long term follow up, and fill irregulary shaped cavities completely (Kasios TCP 2010).

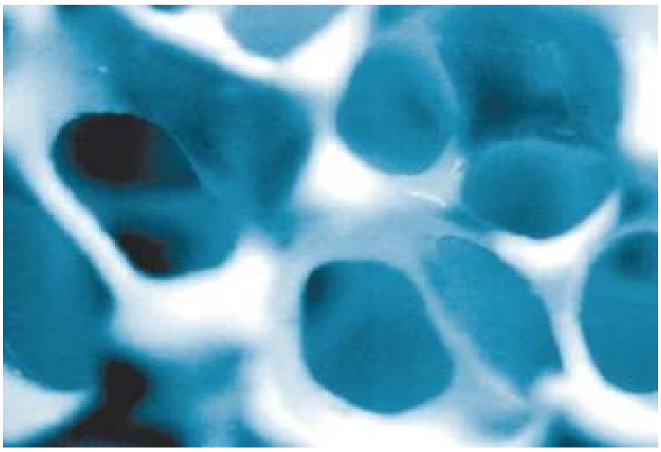

Figure 2.3: Synthetic bone microscopic view.

Source: Kasios TCP 2010

2.5 IMPACT LOAD

In mechanics, an impact is a high force or shock applied over a short time period when two or more bodies collide. Such a force or acceleration usually has a greater effect than a lower force applied over a proportionally longer time period of time. The effect depends critically on the relative velocity of the bodies to one another.

2.6 LAB BASED TEST

Impact in laboratory scale is testing an object's ability to resist high-rate loading. Alternatively, it is a test for determining the energy absorbed in fracturing a test piece at high velocity. Most of us think of it as one object striking another object at a relatively high speed. There are basically two types of impact tests: pendulum and drop weight depending on how the load is applied. It can be further classified as Izod, Charpy, and tensile impact from view point of specimen geometry and size. (Instron 2010).

2.6.1 Pendulum Testing

The first attempts at obtaining this value were done by means of a swing pendulum. A pendulum of a known weight is hoisted to a known height on the opposite side of a pivot point. By calculating the acceleration due to gravity (32.2 ft/sec2 or 9.8 m/sec2), the engineer knows that the weight falling from a set height will contain a certain amount of impact energy at the bottom of the swing. By clamping or supporting a specimen on the bottom, the sample can be released to strike and break the specimen. The pendulum will continue to swing up after the break event to a height somewhat lower than that of a free swing. The engineer can use this lower final height point to calculate the energy that was lost in breaking the specimen. Many pendulum machines will incorporate a pointer and energy reading device so that calculation is unnecessary. Examples of pendulum testing are Charpy and Izod testing (Instron 2010). Figure 2.4 shows a typical Izod impact testing machine.

Figure 2.4: Analog Charpy Izod Impact Testing Machine FIT 300

Source: Fine Manufacturing Industries 2010

2.6.2 Drop Weight Impact Test

A second method was to drop a weight in a vertical direction, with a tube or rails to guide it during the "free fall." With the height and weight known, impact energy can be calculated. In the early days, there was no way to measure impact velocity, so engineers had to assume no friction in the guide mechanism. Since the falling weight either stopped dead on the test specimen, or destroyed it completely in passing through, the only results that could be obtained were of a pass/fail nature.

Falling weight impact has several key advantages over other methods.

1. It is applicable for molded samples, molded parts, etc.
2. It is unidirectional with no preferential direction of failure. Failures originate at the weakest point in the sample and propagate from there.
3. Samples don't have to shatter to be considered failures. Failure can be defined by deformation, crack initiation, or complete fracture, depending on the requirements.

These factors make falling weight testing a better simulation of functional impact exposures, and therefore closer to real-life conditions. However, there are drawbacks to uninstrumented falling weight and Gardener or Gardner weight drop testing (Instron 2010).

Figure 2.5: Gardner Impact Tester

Source: Qualitest 2010

2.7 FINITE ELEMENT THEORY

In dynamic analysis, lagrangian, L is defined by

$$L = T - \pi \tag{2.1}$$

where T is the kinetic energy and π is the potential energy

`L also can be expressed in terms of the generalized variables (q_1, q_2,…, q_n, $\dot{q}_1, \dot{q}_2, \dots, \dot{q}_n$) where

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_i}\right) - \frac{\partial L}{\partial q_i} = 0 \qquad i = 1\ to\ n \tag{2.2}$$

For solid body with distributed mass, as illustrated in Figure 2.6,

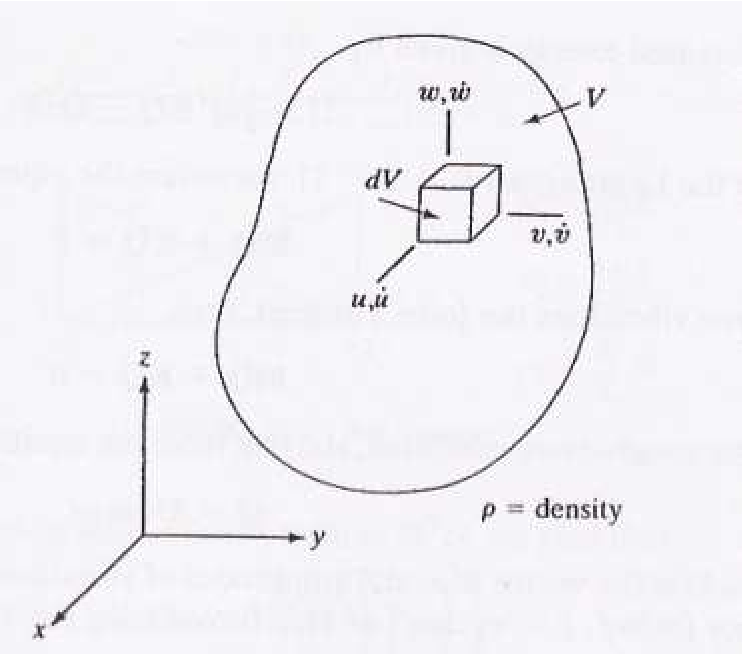

Figure 2.6: Body with distributed mass

Source: Introduction to finite element in engineering